Stratified Ocean Mixing.

FINAL TECHNICAL REPORT

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Introduction:

The aim of this investigation was to shed light on some fundamental issues pertinent to the formation of intrusions and fronts and turbulent mixing in stratified fluids, with the hope that the results will be of use in understanding and modeling of oceanic mixing processes. Two different, but somewhat related, investigations were performed, namely; (i) the formation of intrusions due to the collapse of turbulent patches in stratified fluids, and (ii) the influence of molecular diffusion during mixing at a density interface. During the course of these studies, several interesting phenomena were discovered, for most of which theoretical explanations were offered; a summary of the findings is given below and for more details the reader is referred to the respective publications, which are listed at the end of this report.

Summary of the Results:

In the first set of experiments, an isolated turbulent patch was generated in a linearly stratified fluid by an oscillating grid which horizontally spans only a portion of the fluid. The grid oscillations were sustained and the evolution of the mixed layer was monitored using various flow visualization techniques and more quantitative flow diagnostics methods such as laser-Doppler anemometer and conductivity probe measurements. It was found that the patch initially grows in the vertical direction as in a non-stratified fluid, but its growth is drastically reduced at a non-dimensional time of $Nt = 4$, where N is the stability frequency of the stratification. The size of the patch at this instance was found to scale well with the Ozmidov and buoyancy length-scales. Thereafter, the patch collapses with a typical time scale of the order $Nt = 5 - 8$, whence a horizontally propagating intrusion is generated; the intrusion flows along its equilibrium density level. The collapse of the mixed fluid from the patch also generates an outward radiating internal-wave field whose dominant frequency is approximately $0.9N$. In addition to these waves, a field of (breaking) internal waves was found to remain trapped within the interfacial region that separates the turbulent and outer stratified layers.

Length-scale measurements showed that the size of the turbulent patch scales well with the overturning length-scale, but no simple linear dependence between the size of the patch and the Thorpe length-scale could be discerned. The average speed of the intrusion is constant, and the characteristics of propagation of the intrusion front could be explained using a hydraulic model. The forward propagating internal-wave modes were found to play an important role in the energetics of the intrusion spreading.

Way before the nose of the intrusion reaches the end walls of the tank, the intrusion slows down due to the arrival of a slug of fluid, pushed ahead of the intrusion, at the end walls (upstream blocking). After awhile, the intrusion becomes completely blocked by the end walls and the mixed region surrounding the grid starts growing in the vertical direction. It was, however, found that this subsequent growth is controlled by the secondary flows that are developed at the edges of the patch, rather than by the conventional wave-breaking at the entrainment interface.

The motive of the second set of experiments was to investigate how and when a density interface subjected to turbulence can become strongly influenced by the molecular diffusion. To this end, a series of experiments were performed using a conventional oscillating-grid mixing box apparatus, with temperature stratification. The results revealed that molecular diffusion becomes important when the bulk Richardson number of the interface exceeds a critical value, the latter being a function of the Peclet number of the flow. A model was developed to predict the onset of molecular diffusive effects by assuming that the conventional mixing mechanism - breaking of the interfacial waves - becomes inoperative when the rate of energy fed into the waves becomes the same order as the dissipation rate of kinetic energy of the waves by internal viscous friction. The model predictions were compared with the experimental results and a good agreement was found between the two.

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